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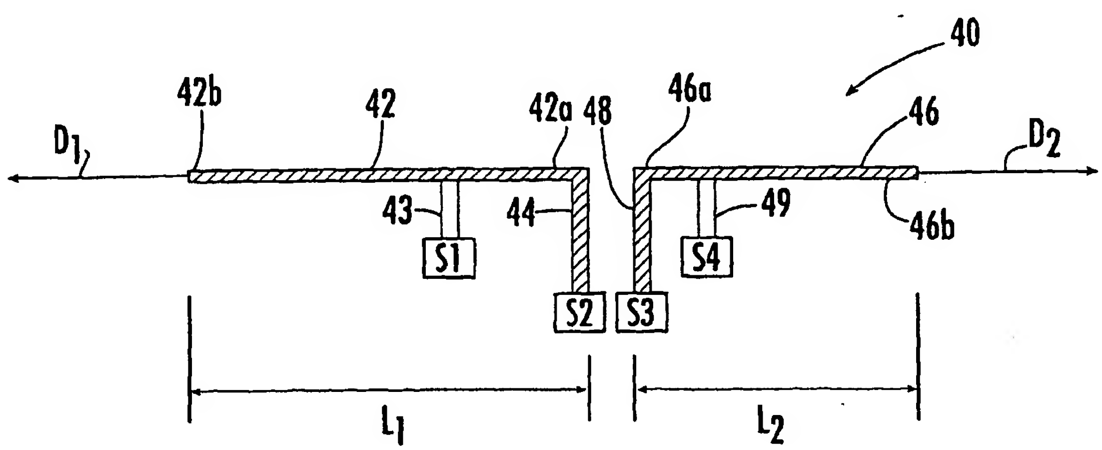
(54) Title: CONVERTIBLE DIPOLE/INVERTED-F ANTENNAS AND WIRELESS COMMUNICATORS INCORPORATING THE SAME



(57) **Abstract:** Multiple frequency band antennas having first and second conductive branches are provided for use within wireless communications devices, such as radiotelephones. First and second conductive branchesare in adjacent, spaced-apart relationship. First and second signal feeds extend from the first conductive branch and terminate at respective first and second switches. Third and fourth signal feeds extend from the second conductive branch and terminate at respective third and fourth switches. The first and second conductive branches can jointly radiate as a dipole antenna in a first frequency band when the first and fourth switches are open, and when the second and third switches electrically connect the second and third feeds to a first receiver/transmitter. Antenna structure may be changed by reconfiguring the various switches. For example, the first and second conductive branches may radiate separately as respective inverted-F antennas, or may radiate independently as monopole antennas.

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CONVERTIBLE DIPOLE/INVERTED-F ANTENNAS AND WIRELESS COMMUNICATORS INCORPORATING THE SAME

FIELD OF THE INVENTION

The present invention relates generally to antennas, and more particularly to antennas used with wireless communications devices.

BACKGROUND OF THE INVENTION

Radiotelephones generally refer to communications terminals which provide a wireless communications link to one or more other communications terminals. Radiotelephones may be used in a variety of different applications, including cellular telephone, land-mobile (*e.g.*, police and fire departments), and satellite communications systems. Radiotelephones typically include an antenna for transmitting and/or receiving wireless communications signals. Historically, monopole and dipole antennas have been employed in various radiotelephone applications, due to their simplicity, wideband response, broad radiation pattern, and low cost.

However, radiotelephones and other wireless communications devices are undergoing miniaturization. Indeed, many contemporary radiotelephones are less than 11 centimeters in length. As a result, there is increasing interest in small antennas that can be

utilized as internally-mounted antennas for radiotelephones.

In addition, it is becoming desirable for radiotelephones to be able to operate within multiple frequency bands in order to utilize more than one communications system. For example, GSM (Global System for Mobile) is a digital mobile telephone system that operates from 880 MHz to 960 MHz. DCS (Digital Communications System) is a digital mobile telephone system that operates from 1710 MHz to 1880 MHz. The frequency bands allocated for cellular AMPS (Advanced Mobile Phone Service) and D-AMPS (Digital Advanced Mobile Phone Service) in North America are 824-894 MHz and 1850-1990 MHz, respectively. Since there are two different frequency bands for these systems, radiotelephone service subscribers who travel over service areas employing different frequency bands may need two separate antennas unless a dual-frequency antenna is used.

In addition, radiotelephones may also incorporate Global Positioning System (GPS) technology and Bluetooth wireless technology. GPS is a constellation of spaced-apart satellites that orbit the Earth and make it possible for people with ground receivers to pinpoint their geographic location. Bluetooth technology provides a universal radio interface in the 2.45 GHz frequency band that enables portable electronic devices to connect and communicate wirelessly via short-range ad hoc networks. Accordingly, radiotelephones incorporating these technologies may require additional antennas tuned for the particular frequencies of GPS and Bluetooth.

Inverted-F antennas are designed to fit within the confines of radiotelephones, particularly radiotelephones undergoing miniaturization. As is well

known to those having skill in the art, inverted-F antennas typically include a linear (*i.e.*, straight) conductive element that is maintained in spaced apart relationship with a ground plane. Examples of inverted-F antennas are described in U.S. Patent Nos. 5,684,492 and 5,434,579 which are incorporated herein by reference in their entirety.

Conventional inverted-F antennas, by design, resonate within a narrow frequency band, as compared with other types of antennas, such as helices, monopoles and dipoles. In addition, conventional inverted-F antennas are typically large. Lumped elements can be used to match a smaller non-resonant antenna to an RF circuit. Unfortunately, such an antenna may be narrow band and the lumped elements may introduce additional losses in the overall transmitted/received signal, may take up circuit board space, and may add to manufacturing costs.

Unfortunately, it may be unrealistic to incorporate multiple antennas within a radiotelephone for aesthetic reasons as well as for space-constraint reasons. In addition, some way of isolating multiple antennas operating simultaneously in close proximity within a radiotelephone may also be necessary. As such, a need exists for small, internal radiotelephone antennas that can operate within multiple frequency bands.

SUMMARY OF THE INVENTION

In view of the above discussion, the present invention can provide compact antennas that can radiate within multiple frequency bands for use within wireless communications devices, such as radiotelephones. An antenna according to an embodiment of the present invention may include first and second conductive branches in adjacent, spaced-apart, mirror-image

relationship. The first conductive branch may include first and second signal feeds extending therefrom, and the second conductive branch may include third and fourth signal feeds extending therefrom.

The first and second signal feeds terminate at respective first and second switches, such as micro-electromechanical systems (MEMS) switches. The first switch is configured to selectively connect the first signal feed to a receiver and/or a transmitter that receives and/or transmits wireless communications signals, or to maintain the first signal feed in an open circuit (*i.e.*, the first switch can be open). The second switch is configured to selectively connect the second signal feed to the same or a different receiver and/or transmitter, or to ground, or to maintain the second signal feed in an open circuit (*i.e.*, the second switch can be open).

The third and fourth feeds terminate at respective third and fourth switches, such as MEMS switches. The third switch is configured to selectively connect the third feed to the same or a different receiver and/or transmitter, or to ground, or to maintain the third feed in an open circuit (*i.e.*, the third switch can be open). The fourth switch is configured to selectively connect the fourth feed to the same or a different receiver and/or transmitter, or to maintain the fourth feed in an open circuit (*i.e.*, the fourth switch can be open).

The first and second conductive branches can jointly radiate as a dipole antenna in a first frequency band when the first and fourth switches are open, and when the second and third switches electrically connect the second and third feeds to a first receiver. The first conductive branch can radiate as an inverted-F antenna in

a second frequency band different from the first frequency band when the third and fourth switches are open, when the first switch is electrically connected to a second receiver, and when the second switch is electrically connected to ground. In addition, the first or second conductive branches can radiate independently as separate monopole antennas.

The first and second conductive branches can also radiate as separate inverted-F antennas in respective different frequency bands. For example, the first conductive branch can radiate as an inverted-F antenna when the first switch is electrically connected to a receiver, and when the second switch is electrically connected to ground. The second conductive branch can radiate as an inverted-F antenna when the third switch is electrically connected to ground, and when the fourth switch is electrically connected to a different receiver.

Antennas according to the present invention may be used with multiple receivers and/or transmitters, and multiple combinations of receivers and/or transmitters. Exemplary receivers and/or transmitters may include, but are not limited to, AMPS receivers/transmitters, PCS receivers/transmitters, GSM receivers/transmitters, DCS receivers/transmitters, GPS receivers, and Bluetooth receivers. For example, when the first and second conductive branches jointly radiate as a dipole antenna, the second and third switches may electrically connect the second and third feeds to a GSM transceiver. When the antenna structure is changed by reconfiguring the various switches as described above, the first and second conductive branches may be electrically connected to different receivers/transmitters. For example, the first conductive branch may radiate as an inverted-F antenna for a GPS receiver and the second conductive branch may

radiate as an inverted-F antenna for a Bluetooth receiver.

According to additional embodiments of the present invention, portions (or all) of the first and second conductive branches may be disposed on or within one or more dielectric substrates. In addition, antennas according to the present invention may include first and second conductive branches with different configurations and with different effective electrical lengths.

Antennas according to the present invention may be particularly well suited for use within a variety of communications systems utilizing different frequency bands. Furthermore, because of their compact size, antennas according to the present invention may be easily incorporated within small communications devices. Furthermore, antennas according to the present invention may be well suited for use with receive-only applications such as GPS.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view of an exemplary radiotelephone within which an antenna according to the present invention may be incorporated.

Fig. 2 is a schematic illustration of a conventional arrangement of electronic components for enabling a radiotelephone to transmit and receive telecommunications signals.

Fig. 3 is a perspective view of a conventional planar inverted-F antenna.

Fig. 4A schematically illustrates an antenna according to the present invention that is convertible between a dipole structure and either one or more inverted-F antenna structures or monopole structures.

Fig. 4B illustrates the antenna of **Fig. 4A** wherein the first and fourth switches are open, and the second and third switches electrically connect the second and third feeds to a receiver such that the first and second conductive branches jointly radiate as a dipole antenna in a first frequency band.

Fig. 4C illustrates the antenna of **Fig. 4A** wherein the third and fourth switches are open to electrically isolate the second conductive branch, the first switch is electrically connected to a second receiver, and the second switch is electrically connected to ground such that the first conductive branch can radiate as an inverted-F antenna in a second frequency band different from the first frequency band of the dipole antenna structure of **Fig. 4B**.

Fig. 4D illustrates the antenna of **Fig. 4A** wherein the first switch is electrically connected to a receiver, and the second switch is electrically connected to ground such that the first conductive branch can radiate as an inverted-F antenna in a second frequency band different from the first frequency band of the dipole antenna structure of **Fig. 4B**, and wherein the third switch is electrically connected to ground, and the fourth switch is electrically connected to a different receiver such that the second conductive branch can radiate as an inverted-F antenna in a third frequency band different from the first and second frequency bands.

Fig. 5 schematically illustrates the antenna of **Fig. 4A** in an installed position within a wireless communications device, such as a radiotelephone.

Fig. 6A is a side elevation view of a dielectric substrate having first and second conductive branches disposed thereon, according to another embodiment of the present invention, and wherein the

dielectric substrate is in adjacent, overlying relationship with a ground plane.

Fig. 6B is a side elevation view of a dielectric substrate having first and second conductive branches disposed therein, according to another embodiment of the present invention, and wherein the dielectric substrate is in adjacent, overlying relationship with a ground plane.

Fig. 7A schematically illustrates the antenna of **Fig. 4A** wherein the first switch is open, the second switch is connected to a receiver or transmitter, the third switch is connected to the receiver or transmitter, and the fourth switch is open.

Fig. 7B is a graph of the VSWR performance of the antenna of **Fig. 7A**.

Fig. 8A schematically illustrates the antenna of **Fig. 4A** wherein the first switch is connected to a first receiver or a first transmitter, the second switch is connected to ground, the third switch is open or is connected to ground, and the fourth switch is open or is connected to a second receiver or a second transmitter.

Fig. 8B is a graph of the VSWR performance of the antenna of **Fig. 8A**.

Fig. 9A schematically illustrates the antenna of **Fig. 4A** wherein the first switch is open or connected to a first receiver or a first transmitter, the second switch is open or is connected to ground, the third switch is connected to ground, and the fourth switch is connected to a second receiver or transmitter.

Fig. 9B is a graph of the VSWR performance of the antenna of **Fig. 9A**.

DETAILED DESCRIPTION OF THE INVENTION

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, the thickness of layers and regions may be exaggerated for clarity. Like numbers refer to like elements throughout the description of the drawings. It will be understood that when an element such as a layer, region or substrate is referred to as being "on" another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements present.

Referring now to **Fig. 1**, a radiotelephone **10**, within which antennas according to various embodiments of the present invention may be incorporated, is illustrated. The housing **12** of the illustrated radiotelephone **10** includes a top portion **13** and a bottom portion **14** connected thereto to form a cavity therein. Top and bottom housing portions **13**, **14** house a keypad **15** including a plurality of keys **16**, a display **17**, and electronic components (not shown) that enable the radiotelephone **10** to transmit and receive radiotelephone communications signals.

A conventional arrangement of electronic components that enable a radiotelephone to transmit and receive radiotelephone communication signals is shown

schematically in **Fig. 2**, and is understood by those skilled in the art of radiotelephone communications. An antenna **22** for receiving and transmitting radiotelephone communication signals is electrically connected to a radio-frequency transceiver **24** that is further electrically connected to a controller **25**, such as a microprocessor. The controller **25** is electrically connected to a speaker **26** that transmits a remote signal from the controller **25** to a user of a radiotelephone. The controller **25** is also electrically connected to a microphone **27** that receives a voice signal from a user and transmits the voice signal through the controller **25** and transceiver **24** to a remote device. The controller **25** is electrically connected to a keypad **15** and display **17** that facilitate radiotelephone operation.

As is known to those skilled in the art of communications devices, an antenna is a device for transmitting and/or receiving electrical signals. A transmitting antenna typically includes a feed assembly that induces or illuminates an aperture or reflecting surface to radiate an electromagnetic field. A receiving antenna typically includes an aperture or surface focusing an incident radiation field to a collecting feed, producing an electronic signal proportional to the incident radiation. The amount of power radiated from or received by an antenna depends on its aperture area and is described in terms of gain.

Radiation patterns for antennas are often plotted using polar coordinates. Voltage Standing Wave Ratio (VSWR) relates to the impedance match of an antenna feed point with a feed line or transmission line of a communications device, such as a radiotelephone. To radiate radio frequency (RF) energy with minimum loss, or to pass along received RF energy to a radiotelephone

receiver with minimum loss, the impedance of a radiotelephone antenna is conventionally matched to the impedance of a transmission line or feed point.

Conventional radiotelephones typically employ an antenna which is electrically connected to a transceiver operably associated with a signal processing circuit positioned on an internally disposed printed circuit board. In order to maximize power transfer between an antenna and a transceiver, the transceiver and the antenna are preferably interconnected such that their respective impedances are substantially "matched," *i.e.*, electrically tuned to filter out or compensate for undesired antenna impedance components to provide a 50 Ohm (Ω) (or desired) impedance value at the feed point.

Referring now to **Fig. 3**, a conventional planar inverted-F antenna is illustrated. The illustrated antenna **30** includes a linear conductive element **32** maintained in spaced apart relationship with a ground plane **34**. Conventional inverted-F antennas, such as that illustrated in **Fig. 3**, derive their name from a resemblance to the letter "F." The illustrated conductive element **32** is grounded to the ground plane **34** as indicated by **36**. A hot RF connection **37** extends from underlying RF circuitry through the ground plane **34** to the conductive element **32**.

Referring now to **Fig. 4A**, a multiple frequency band antenna **40** according to the present invention that is convertible between a dipole structure, one or more inverted-F structures, and independent monopole structures is illustrated. The illustrated antenna **40** includes a first conductive branch **42** having opposite first and second ends **42a**, **42b**. First and second feeds **43**, **44** extend from the first conductive branch **42** adjacent the first end **42a**, as illustrated. The first and

second feeds **43**, **44** terminate at respective first and second switches **S1**, **S2**.

A second conductive branch **46** is in adjacent, spaced-apart, mirror-image relationship with the first conductive branch **42**, as illustrated. However, it is understood that the first and second conductive branches **42**, **46** need not be in mirror-image relationship with each other. The first and second conductive branches **42**, **46** may have various configurations relative to each other.

In the illustrated embodiment, the first conductive branch extends along a first direction $\mathbf{D_1}$, and the second conductive branch extends along a second, opposite direction $\mathbf{D_2}$. The first and second directions $\mathbf{D_1}$, $\mathbf{D_2}$ may be generally parallel, opposite directions. However, antennas according to the present invention may have first and second conductive branches that extend along respective directions that are not parallel.

The first conductive branch and the second conductive branch each have first and second electrical lengths $\mathbf{L_1}$, $\mathbf{L_2}$, respectively. The first and second electrical lengths may be the same or may be different. As would be understood by those of skill in the art, the first and second electrical lengths $\mathbf{L_1}$, $\mathbf{L_2}$ are tuning parameters of the antenna **40**.

The second conductive branch **46** has opposite third and fourth ends **46a**, **46b**. The third end **46a** is positioned adjacent the first end **42a** of the first conductive branch **42**, as illustrated. Third and fourth feeds **48**, **49** extend from the second conductive branch **46** adjacent the second conductive branch third end **46a**, as illustrated. The third and fourth feeds **48**, **49** terminate at respective third and fourth switches **S3**, **S4**.

Preferably, the first, second, third, and fourth switches **S1**-**S4** are micro-electromechanical systems

(MEMS) switches. A MEMS switch is an integrated micro device that combines electrical and mechanical components fabricated using integrated circuit (IC) compatible batch-processing techniques and can range in size from micrometers to millimeters. MEMS devices in general, and MEMS switches in particular, are understood by those of skill in the art and need not be described further herein. Examples of MEMS switches are described in U.S. Patent No. 5,909,078. It also will be understood that conventional switches, including relays and actuators, may be used.

The first switch **S1** is configured to selectively connect the first feed **43** to either a receiver that receives wireless communications signals, or to maintain the first feed **43** in an open circuit (*i.e.*, the first switch **S1** can be open to electrically isolate the first feed **43**). The second switch **S2** is configured to selectively connect the second feed **44** to a receiver that receives wireless communications signals, or a transmitter that transmits wireless communications signals, or to ground, or to maintain the second feed **44** in an open circuit (*i.e.*, the second switch **S2** can be open to electrically isolate the second feed **44**).

Although described herein with respect to receivers that receive wireless communications signals and transmitters that transmit wireless communications signals, it is understood that antennas according to the present invention may be utilized with transceivers that both transmit and receive wireless communications signals. Exemplary transceivers include radiotelephone transceivers that transmit and receive radiotelephone communications signals.

Still referring to **Fig. 4A**, the third switch **S3** is configured to selectively connect the third feed **48** to

a receiver that receives wireless communications signals, or to a transmitter that transmits wireless communications signals, or to ground, or to maintain the third feed **48** in an open circuit (*i.e.*, the third switch **S3** can be open to electrically isolate the third feed). The fourth switch **S4** is configured to selectively connect the fourth feed **49** to a receiver that receives wireless communications signals, or to a transmitter that transmits wireless communications signals, or to maintain the fourth feed **49** in an open circuit (*i.e.*, the fourth switch **S4** can be open to electrically isolate the fourth feed).

The first and second conductive branches **42, 46** can jointly radiate as a dipole antenna in a first frequency band when the first and fourth switches **S1, S4** are open, and when the second and third switches **S2, S3** electrically connect the second and third feeds **44, 48** to a first receiver/transmitter **50** (**Fig. 4B**). By selectively configuring the various switches **S1-S4**, the antenna **40** can be converted into different effective antenna structures that are operative within different frequency bands.

For example, the first conductive branch **42** can radiate as an inverted-F antenna in a second frequency band different from the first frequency band when the third and fourth switches **S3, S4** are open to electrically isolate the second conductive branch **46**, when the first switch **S1** is electrically connected to a second receiver/transmitter **50'**, and when the second switch **S2** is electrically connected to ground (**Fig. 4C**). For example, the first frequency band may be between about 900 MHz and 960 MHz and the second frequency band may be between about 1200 MHz and 1400 MHz. However, it is understood that antennas according to the present

invention may radiate in various frequency bands. The second conductive branch **46** is indicated as electrically isolated in **Fig. 4C** by the absence of shading.

As another example, the first conductive branch **42** can radiate as an inverted-F antenna in a second frequency band different from the first frequency band of the dipole antenna structure when the first switch **S1** is electrically connected to a second receiver/transmitter **50'**, and when the second switch **S2** is electrically connected to ground. In addition, the second conductive branch **46** can radiate as an inverted-F antenna in a third frequency band different from the first and second frequency bands when the third switch **S3** is electrically connected to ground, and when the fourth switch **S4** is electrically connected to a third receiver/transmitter **50"** (**Fig. 4D**). For example, the first frequency band may be between about 900 MHz and 960 MHz, the second frequency band may be between about 1200 MHz and 1400 MHz and the third frequency band may be between about 2200 MHz and 2400 MHz. Again, it is understood that these are only exemplary frequency bands. Antennas according to this embodiment of the present invention may radiate in various different frequency bands.

As yet another example, the first or second conductive branches **42**, **46** of the antenna **40** illustrated in **Fig. 4A** can independently radiate as respective monopole antennas.

Antennas according to the present invention may be used with multiple receivers and/or transmitters, and multiple combinations of receivers and/or transmitters. Exemplary receivers (and/or transmitters) include, but are not limited to, AMPS receivers/transmitters, PCS receivers/transmitters, GSM receivers/transmitters, DCS receivers/transmitters, GPS receivers, and Bluetooth

receivers. For example, when the first and second conductive branches **42**, **46** jointly radiate as a dipole antenna, the second and third switches **S2**, **S3** may electrically connect the second and third feeds **44**, **48** to a GSM transceiver. When the antenna structure is changed by reconfiguring the various switches **S1-S4** as described above, the first and second conductive branches may be electrically connected to different receivers/transmitters. For example, the first conductive branch **42** may radiate as an inverted-F antenna for a GPS receiver and the second conductive branch **46** may radiate as an inverted-F antenna for a Bluetooth receiver.

Referring to **Fig. 5**, the antenna **40** of **Fig. 4A** is illustrated in an installed position within a wireless communications device, such as a radiotelephone (**Fig. 1**). The first and second conductive branches **42**, **46** are maintained in adjacent, spaced-apart relationship with each other and with a ground plane **55**, such as a printed circuit board (PCB) within a radiotelephone (or other wireless communications device), as illustrated. As would be understood by those of skill in the art, the first, second, third, and fourth switches **S1**, **S2**, **S3**, **S4** are electrically connected to circuitry that allows each to be selectively connected to ground, or to a receiver/transmitter, or to an open circuit, as described above. In the illustrated embodiment, the first and fourth switches are open (indicated by **O**) and the second and third switches are electrically connected to a receiver/transmitter (indicated by **RF**) such that the first and second conductive branches **42**, **46** radiate jointly as a dipole antenna.

According to another embodiment, illustrated in **Fig. 6A**, all or portions of the first and second conductive branches **42**, **46** may be formed on a dielectric

substrate **60**, for example by etching a metal layer formed on the dielectric substrate. An exemplary material for use as a dielectric substrate **60** is FR4 or polyimide, which is well known to those having skill in the art of communications devices. However, various other dielectric materials also may be utilized. Preferably, the dielectric substrate **60** has a dielectric constant between about 2 and about 4. However, it is to be understood that dielectric substrates having different dielectric constants may be utilized without departing from the spirit and intent of the present invention.

The antenna **40** of **Fig. 6A** is illustrated in an installed position within a wireless communications device, such as a radiotelephone. The dielectric substrate **60** having the first and second conductive branches **42** disposed thereon is maintained in an adjacent, spaced-apart relationship with a ground plane (PCB) **55**. The first, second, third, and fourth feeds **43, 44, 48, 49** extend through respective apertures **45** in the dielectric substrate **60**. The distance **H** between the dielectric substrate **60** and the ground plane **55** is preferably maintained at between about 2 mm and about 10 mm. However, the distance **H** may be greater than 10 mm and less than 2 mm.

According to another embodiment of the present invention illustrated in **Fig. 6B**, all or portions of the first and second conductive branches **42, 46** may be disposed within a dielectric substrate **60**.

A preferred conductive material out of which the first and second conductive branches **42, 46** of antennas according to the present invention may be formed is copper, typically 0.5 ounce (14 grams) copper. For example, the first and second conductive branches **42, 46** may be formed from copper foil. However, the first and

second conductive branches **42**, **46** according to the present invention may be formed from various conductive materials and are not limited to copper.

Referring now to **Figs. 7A-7B**, the antenna **40** of **Fig. 4A** is illustrated with the first switch **S1** open (indicated by **O**), the second switch **S2** connected to a receiver or transmitter (indicated by **RF**), the third switch **S3** connected to the receiver or transmitter (indicated by **RF**), and the fourth switch **S4** open (indicated by **O**). With the switches in the illustrated configuration, the antenna **40** radiates as a dipole antenna in a frequency band centered around 1850 MHz, as illustrated in **Fig. 7B**. With the illustrated configurations of the switches **S1-S4**, the first and second conductive branches have effective electrical lengths of 45 mm and 30 mm, respectively. In the illustrated embodiment, the first and second feeds **43**, **44** are spaced apart by a distance of 6 mm, and the third and fourth feeds **48**, **49** are spaced apart by a distance of 7 mm. The first and second conductive branches **42**, **46** are spaced apart from a ground plane (not shown) by a distance of 7 mm.

Referring now to **Figs. 8A-8B**, the antenna **40** of **Fig. 4A** is illustrated with the first switch **S1** connected to a first receiver or a first transmitter (indicated by **RF1**), the second switch **S2** is connected to ground (indicated by **G**), the third switch **S3** is open or is connected to ground (indicated by **O/G**), and the fourth switch **S4** is open or is connected to a second receiver or a second transmitter (indicated by **O/RF2**). With the switches in the illustrated configuration, the antenna **40** radiates as an inverted-F antenna in a frequency band centered around 1612 MHz, as illustrated in **Fig. 8B**. With the illustrated configurations of the switches **S1-S4**, the

first and second conductive branches have lengths of 45 mm and 30 mm, respectively. In the illustrated embodiment, the first and second feeds **43, 44** are spaced apart by a distance of 6 mm, and the third and fourth feeds **48, 49** are spaced apart by a distance of 7 mm. The first and second conductive branches **42, 46** are spaced apart from a ground plane (not shown) by a distance of 7 mm.

Referring now to **Figs. 9A-9B**, the antenna **40** of **Fig. 4A** is illustrated with the first switch **S1** open or connected to a first receiver or a first transmitter (indicated by **O/RF1**), the second switch **S2** is open or is connected to ground (indicated by **O/G**), the third switch **S3** is connected to ground (indicated by **G**), and the fourth switch **S4** is connected to a second receiver or transmitter (indicated by **RF2**). With the switches in the illustrated configuration, the antenna **40** radiates as an inverted-F antenna in a frequency band centered around 2391 MHz, as illustrated in **Fig. 9B**. With the illustrated configurations of the switches **S1-S4**, the first and second conductive branches have lengths of 45 mm and 30 mm, respectively. In the illustrated embodiment, the first and second feeds **43, 44** are spaced apart by a distance of 6 mm, and the third and fourth feeds **48, 49** are spaced apart by a distance of 7 mm. The first and second conductive branches **42, 46** are spaced apart from a ground plane (not shown) by a distance of 7 mm.

The foregoing is illustrative of the present invention and is not to be construed as limiting thereof. Although a few exemplary embodiments of this invention have been described, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this

invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the claims. Therefore, it is to be understood that the foregoing is illustrative of the present invention and is not to be construed as limited to the specific embodiments disclosed, and that modifications to the disclosed embodiments, as well as other embodiments, are intended to be included within the scope of the appended claims. The invention is defined by the following claims, with equivalents of the claims to be included therein.

THAT WHICH IS CLAIMED IS:

1. A multiple frequency band antenna, comprising:

a first conductive branch having opposite first and second ends;

first and second feeds extending from the first conductive branch adjacent the first conductive branch first end, wherein the first and second feeds terminate at respective first and second switches, wherein the first switch is configured to selectively connect the first feed to a receiver that receives wireless communications signals, or to a transmitter that transmits wireless communications signals, or to maintain the first feed in an open circuit, and wherein the second switch is configured to selectively connect the second feed to a receiver that receives wireless communications signals, or to a transmitter that transmits wireless communications signals, or to ground, or to maintain the second feed in an open circuit;

a second conductive branch in adjacent, spaced-apart relationship with the first conductive branch and having opposite third and fourth ends; and

third and fourth feeds extending from the second conductive branch adjacent the second conductive branch third end, wherein the third and fourth feeds terminate at respective third and fourth switches, wherein the third switch is configured to selectively connect the third feed to a receiver that receives wireless communications signals, or to a transmitter that transmits wireless communications signals, or to ground, or to maintain the third feed in an open circuit, and wherein the fourth switch is configured to selectively

connect the fourth feed to a receiver that receives wireless communications signals, or to a transmitter that transmits wireless communications signals, or to maintain the fourth feed in an open circuit;

wherein the first and second conductive branches jointly radiate as a dipole antenna in a first frequency band when the first and fourth switches are open to electrically isolate the first and fourth feeds, respectively, and when the second and third switches electrically connect the second and third feeds to a first receiver or to a first transmitter; and

wherein the first conductive branch radiates as an inverted-F antenna in a second frequency band different from the first frequency band, when the first switch is electrically connected to a second receiver or to a second transmitter, and when the second switch is electrically connected to ground.

2. The antenna according to Claim 1 wherein the first conductive branch radiates as an inverted-F antenna in a second frequency band different from the first frequency band when the first switch is electrically connected to a second receiver or to a second transmitter, and when the second switch is electrically connected to ground; and

wherein the second conductive branch radiates as an inverted-F antenna in a third frequency band different from the first and second frequency bands when the third switch is electrically connected to ground, and when the fourth switch is electrically connected to a third receiver or to a third transmitter.

3. The antenna according to Claim 1 wherein the first or second conductive branches independently

radiate as respective monopole antennas.

4. The antenna according to Claim 1 wherein the first and second conductive branches have respective different electrical lengths.

5. The antenna according to Claim 1 wherein the first receiver is selected from the group consisting of AMPS receivers, PCS receivers, GSM receivers, and DCS receivers, and wherein the second receiver is selected from the group consisting of GPS receivers and Bluetooth receivers.

6. The antenna according to Claim 1 wherein the first and second conductive branches are in spaced-apart, mirror-image relationship.

7. The antenna according to Claim 1 wherein the first and second conductive branches extend along generally parallel, opposite directions.

8. The antenna according to Claim 1 wherein the first, second, third, and fourth switches comprise micro-electromechanical systems (MEMS) switches.

9. The antenna according to Claim 1 wherein a portion of at least one of the first and second conductive branches is disposed on a respective surface of a dielectric substrate.

10. The antenna according to Claim 1 wherein a portion of at least one of the first and second conductive branches is disposed within a dielectric substrate.

11. A wireless communicator, comprising:

a housing configured to enclose a receiver that receives wireless communications signals;

a ground plane disposed within the housing; and

a multiple frequency band antenna, comprising:

a first conductive branch having opposite first and second ends, wherein the first conductive branch is in adjacent, spaced-apart relationship with the ground plane;

first and second feeds extending from the first conductive branch adjacent the first conductive branch first end, wherein the first and second feeds terminate at respective first and second switches, wherein the first switch is configured to selectively connect the first feed to a receiver that receives wireless communications signals, or to a transmitter that transmits wireless communications signals, or to maintain the first feed in an open circuit, and wherein the second switch is configured to selectively connect the second feed to a receiver that receives wireless communications signals, or to a transmitter that transmits wireless communications signals, or to ground, or to maintain the second feed in an open circuit;

a second conductive branch in adjacent, spaced-apart relationship with the first conductive branch and having opposite third and fourth ends, wherein the second conductive branch is in adjacent, spaced-apart relationship with the ground plane; and

third and fourth feeds extending from the second conductive branch adjacent the second

conductive branch third end, wherein the third and fourth feeds terminate at respective third and fourth switches, wherein the third switch is configured to selectively connect the third feed to a receiver that receives wireless communications signals, or to a transmitter that transmits wireless communications signals, or to ground, or to maintain the third feed in an open circuit, and wherein the fourth switch is configured to selectively connect the fourth feed to a receiver that receives wireless communications signals, or to a transmitter that transmits wireless communications signals, or to maintain the fourth feed in an open circuit;

wherein the first and second conductive branches jointly radiate as a dipole antenna in a first frequency band when the first and fourth switches are open to electrically isolate the first and fourth feeds, respectively, and when the second and third switches electrically connect the second and third feeds to a first receiver or to a first transmitter; and

wherein the first conductive branch radiates as an inverted-F antenna in a second frequency band different from the first frequency band, when the first switch is electrically connected to a second receiver or to a second transmitter, and when the second switch is electrically connected to ground.

12. The wireless communicator according to Claim 11 wherein the first conductive branch radiates as

an inverted-F antenna in a second frequency band different from the first frequency band when the first switch is electrically connected to a second receiver or to a second transmitter, and when the second switch is electrically connected to ground; and

wherein the second conductive branch radiates as an inverted-F antenna in a third frequency band different from the first and second frequency bands when the third switch is electrically connected to ground, and when the fourth switch is electrically connected to a third receiver or to a third transmitter.

13. The wireless communicator according to Claim 11 wherein the first or second conductive branches independently radiate as monopole antennas.

14. The wireless communicator according to Claim 11 wherein the first and second conductive branches have respective different electrical lengths.

15. The wireless communicator according to Claim 11 wherein the first receiver is selected from the group consisting of AMPS receivers, PCS receivers, GSM receivers, and DCS receivers, and wherein the second receiver is selected from the group consisting of GPS receivers and Bluetooth receivers.

16. The wireless communicator according to Claim 11 wherein the first and second conductive branches are in spaced-apart, mirror-image relationship.

17. The wireless communicator according to Claim 11 wherein the first and second conductive branches extend along generally parallel, opposite directions.

18. The wireless communicator according to Claim 11 wherein the first, second, third, and fourth switches comprise micro-electromechanical systems MEMS switches.

19. The wireless communicator according to Claim 11 wherein a portion of at least one of the first and second conductive branches is disposed on a respective surface of a dielectric substrate.

20. The wireless communicator according to Claim 11 wherein a portion of at least one of the first and second conductive branches is disposed within a dielectric substrate.

21. The wireless communicator according to Claim 11 wherein the wireless communicator comprises a radiotelephone.

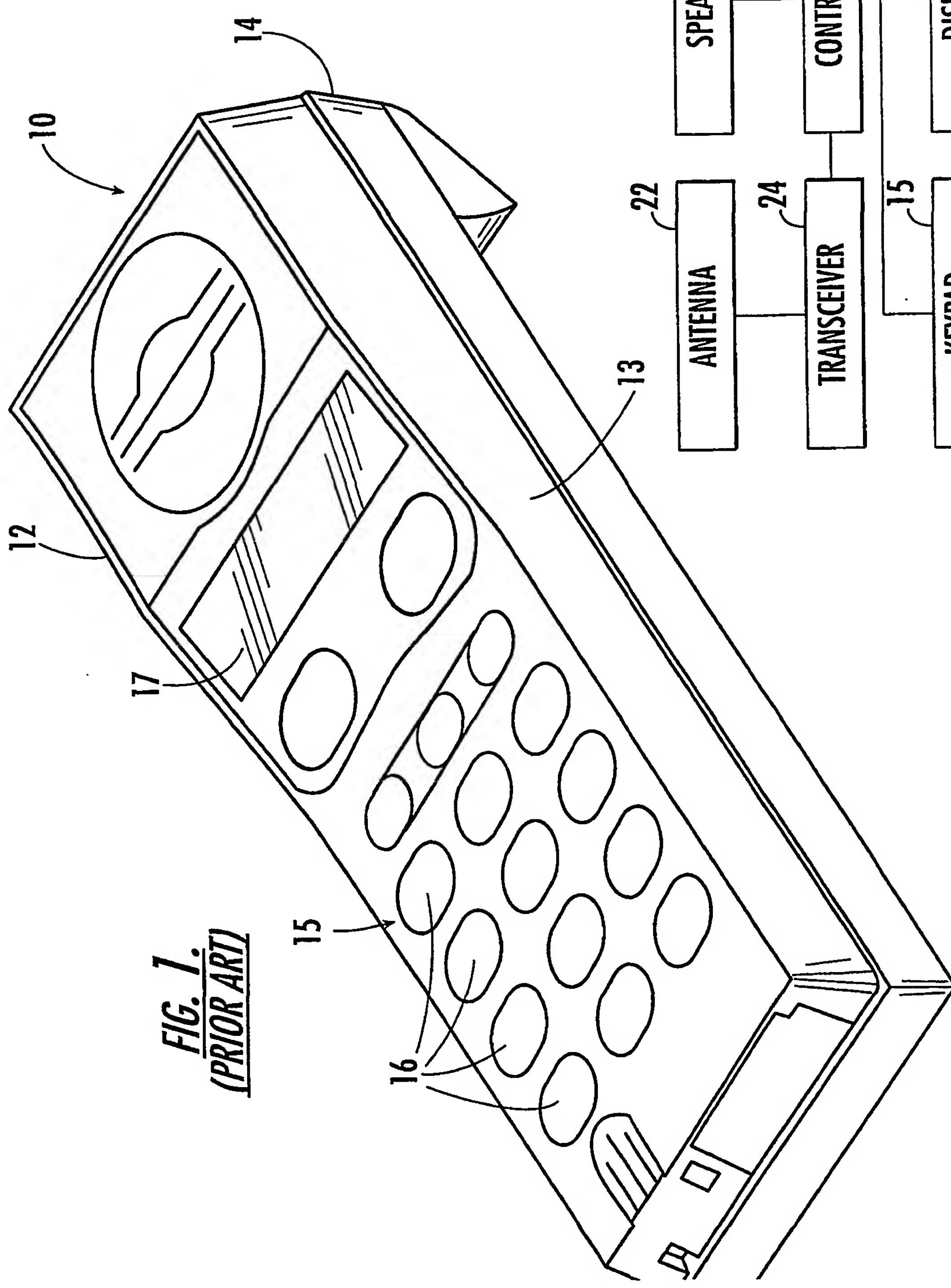


FIG. 1.
(PRIOR ART)

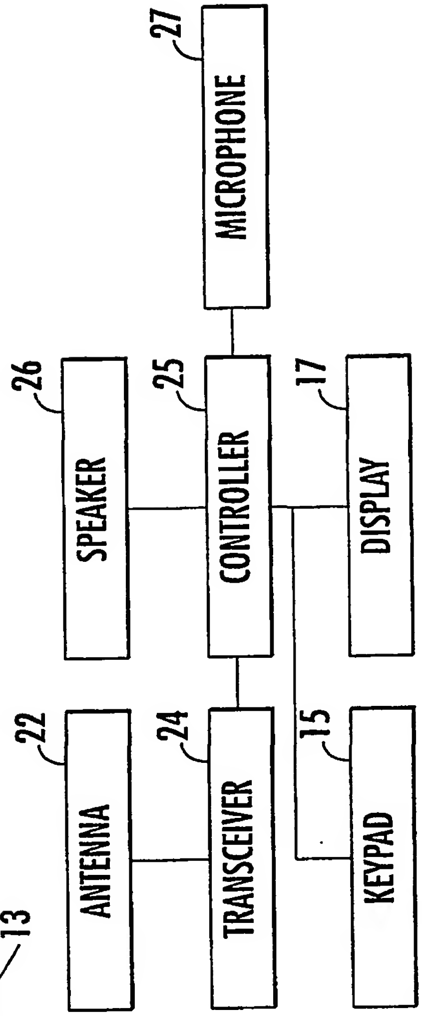


FIG. 2.
(PRIOR ART)

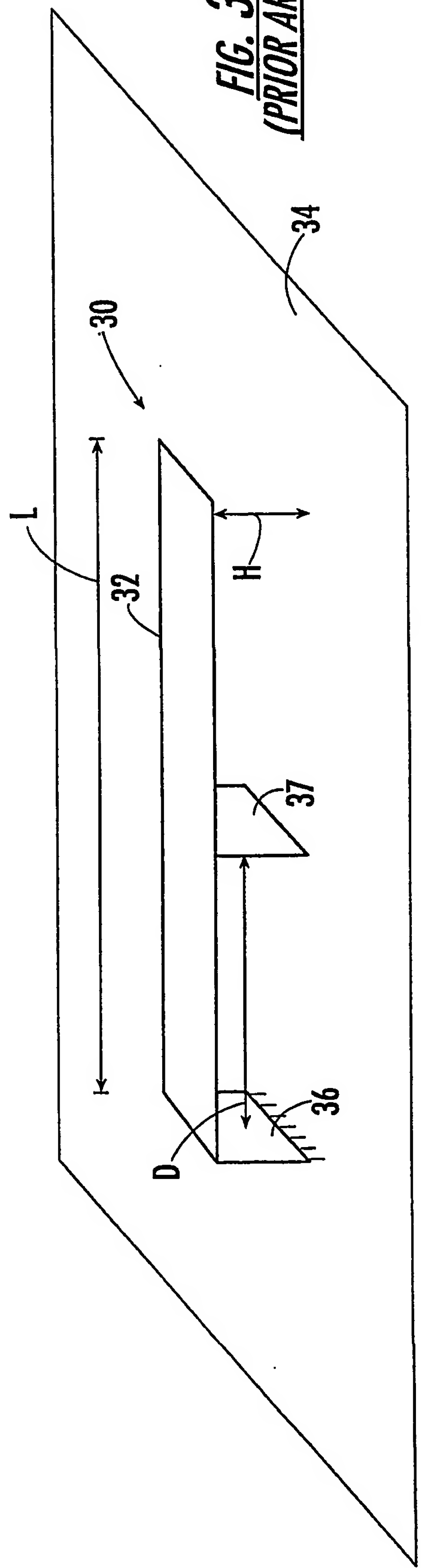


FIG. 3.
(PRIOR ART)

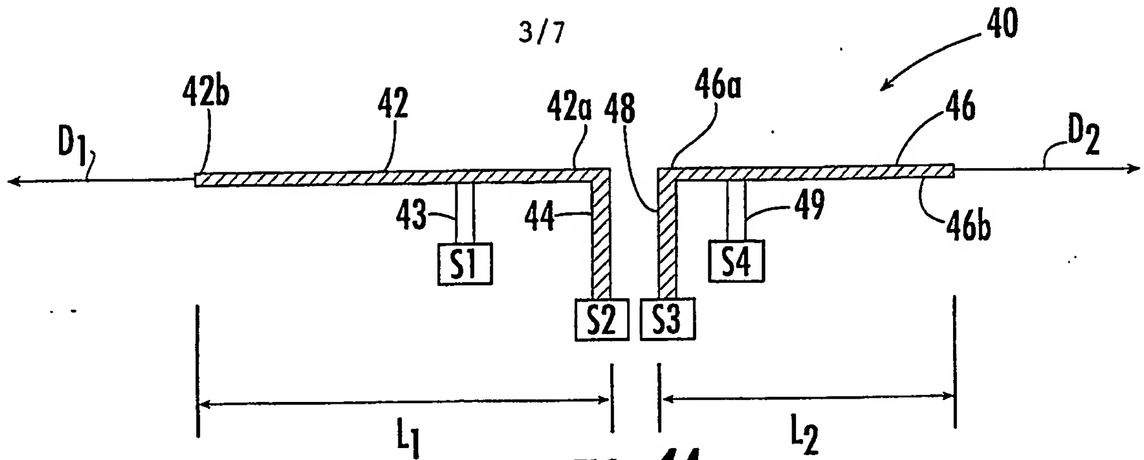


FIG. 4A.

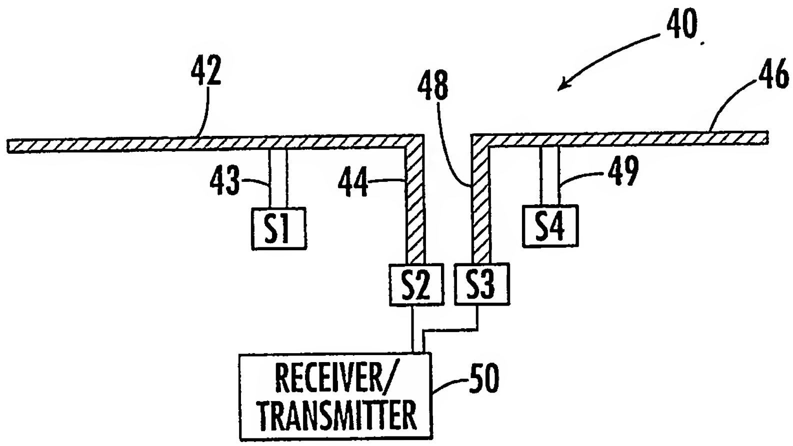


FIG. 4B.

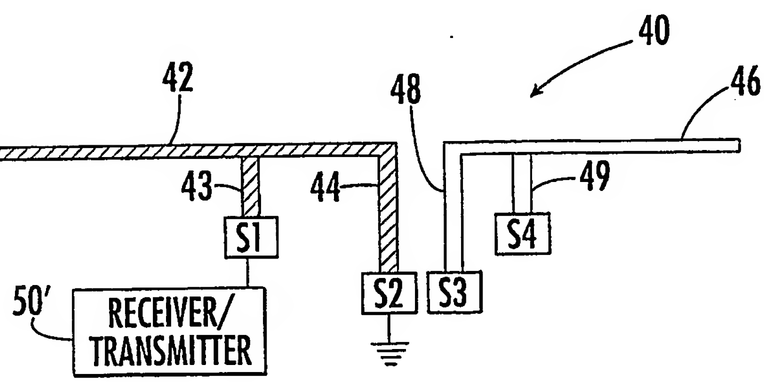


FIG. 4C.

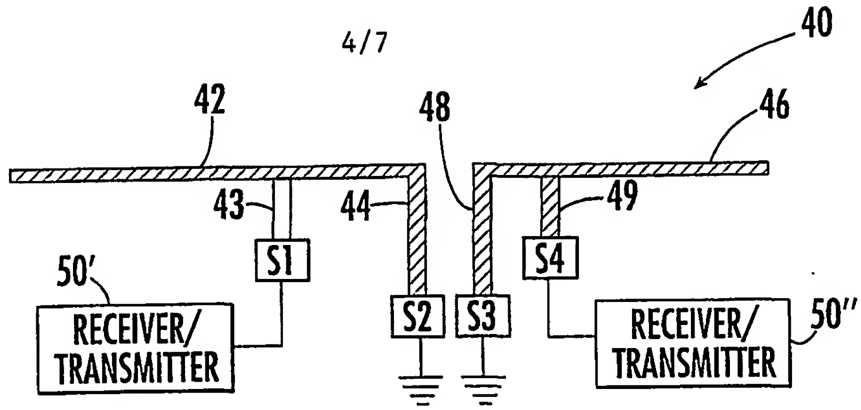
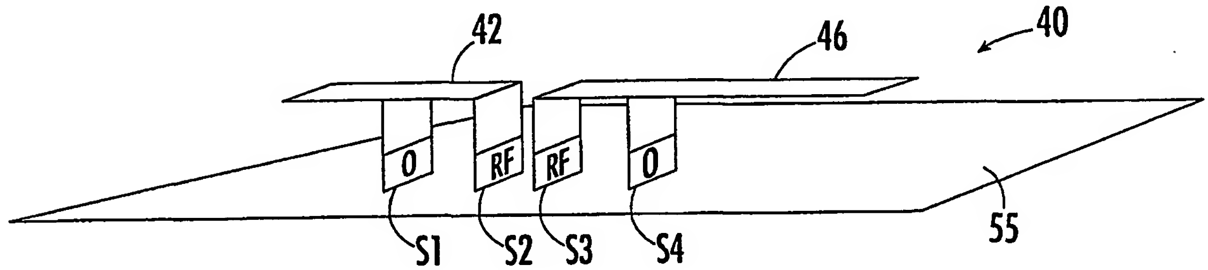


FIG. 4D.



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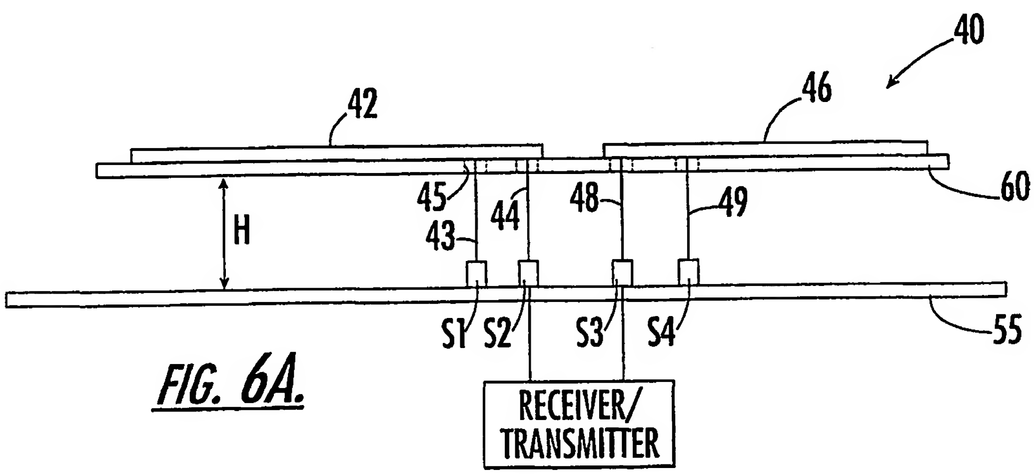


FIG. 6A.

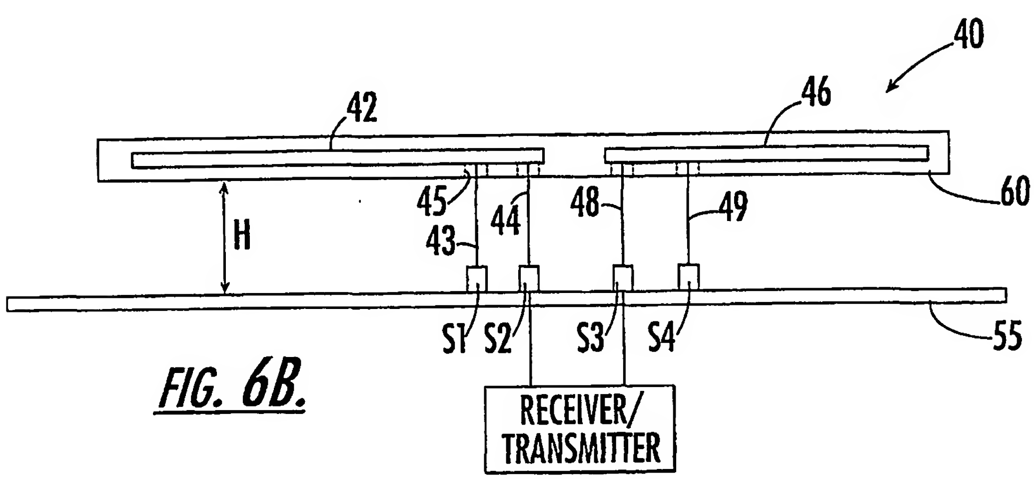
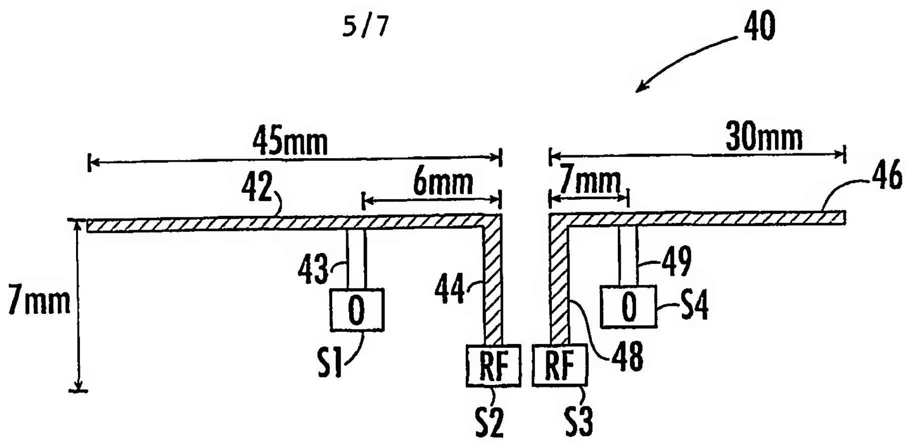


FIG. 6B.

FIG. 7A.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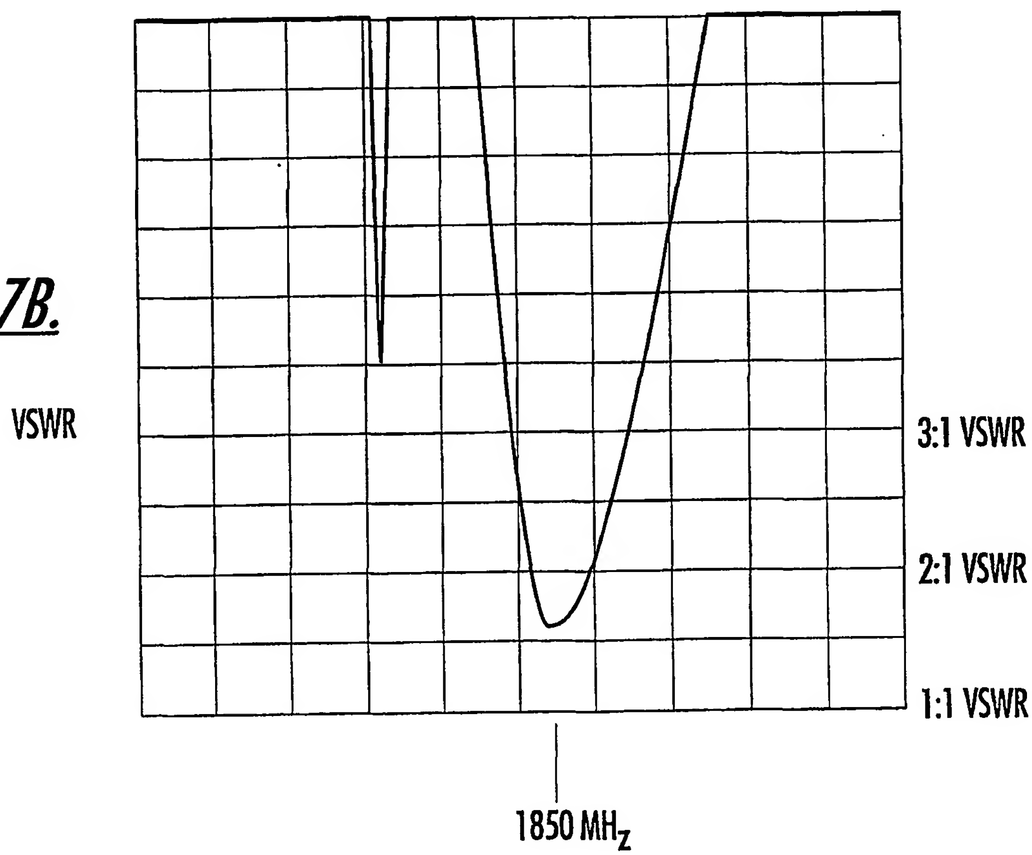
45mm
30mm
42
6mm
7mm
46
7mm
43
44
49
0
0
S4
S1
RF
RF
48
S2
S3

FIG. 7B.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2:1 VSWR
1:1 VSWR
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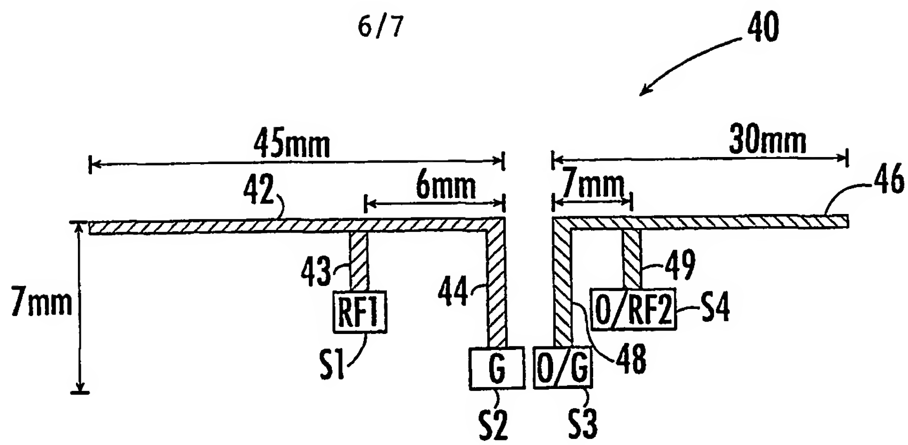
FIG. 8A.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6mm
7mm
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RF1
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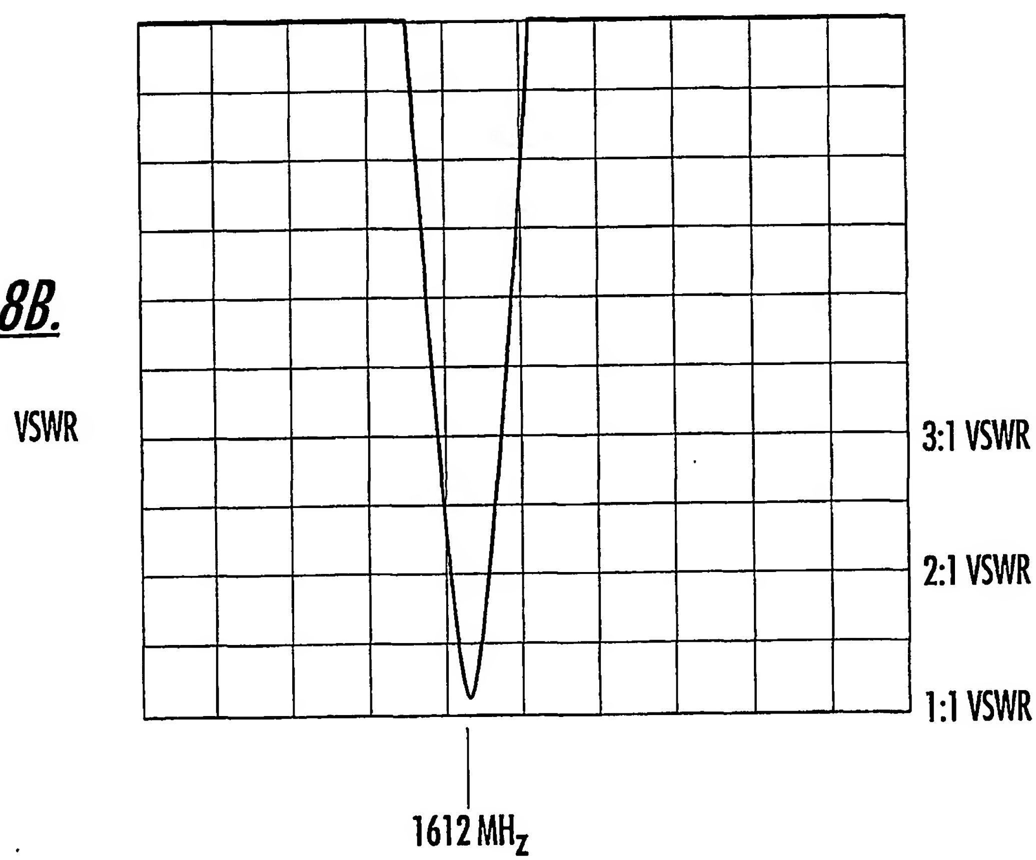
O/RF2
S4
7mm
S1
G
O/G
48
S2
S3

FIG. 8B.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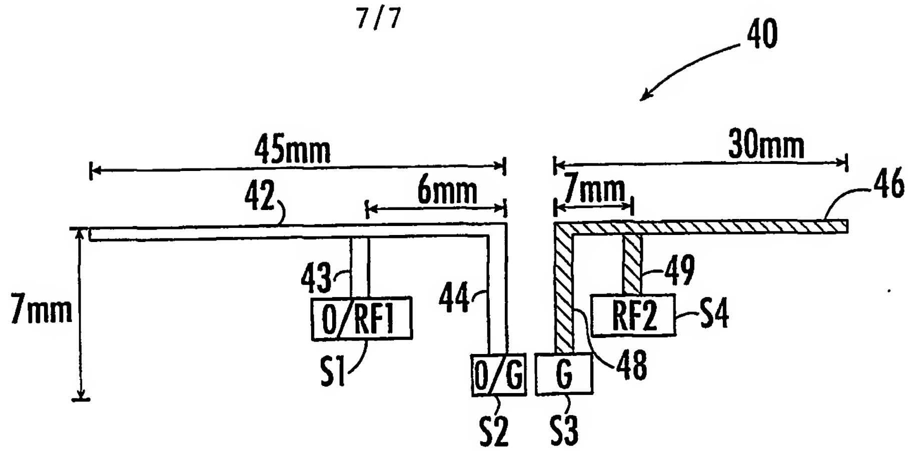
2:1 VSWR
1:1 VSWR
1612 MHz

FIG. 9A.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30mm
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6mm
7mm
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7mm
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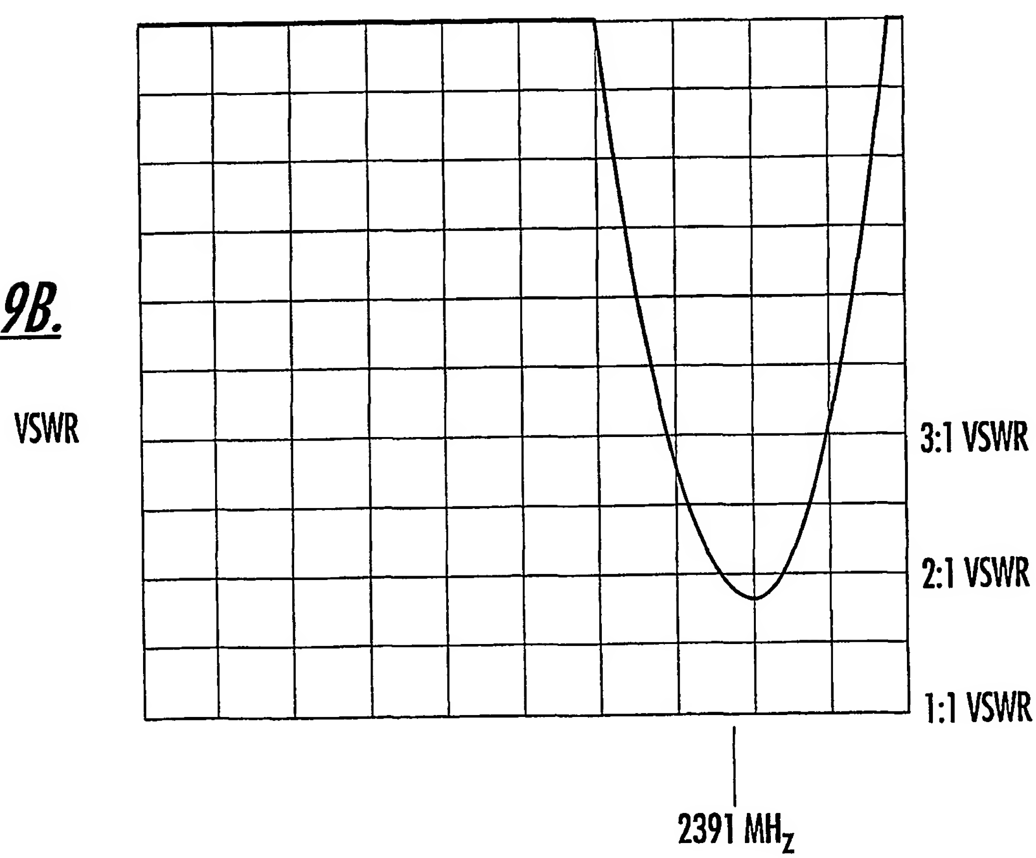
RF2
S4
S1
0/G
G
48
S2
S3

FIG. 9B.


VSWR
3:1 VSWR
2:1 VSWR
1:1 VSWR
2391 MHz

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/12179

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01Q9/04 H01Q1/24 H01Q9/20 H01Q9/30

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 892 459 A (NOKIA MOBILE PHONES LTD) 20 January 1999 (1999-01-20) column 4-7; figures 1-5	1,11
A	PATENT ABSTRACTS OF JAPAN vol. 1999, no. 04, 30 April 1999 (1999-04-30) & JP 11 008512 A (TOSHIBA CORP), 12 January 1999 (1999-01-12) abstract; figures 1,2	1,11
A	US 5 926 150 A (CROOK GENTRY ET AL) 20 July 1999 (1999-07-20) figures 1,5	1,11

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"P" document published prior to the international filing date but later than the priority date claimed

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 September 2001	01/10/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Ribbe, J

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int ›nal Application No

PCT/US 01/12179

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0892459 A	20-01-1999	FI 972897 A	09-01-1999
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